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ADRIATICO CONFERENCE ON FOURIER OPTICS AND HOLOGRAPHY

6 - 9 March 1990

INTERCONNECTS IN OPTICAL COMPUTERS

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INTERCONNECTS IN OPTICAL COMPUTERS

(or, also,

OPTICAL INTERCONNECTS IN COMPUTERS)

F. Chavel, Institut d'Optique (CNRS) Orsay. F

Outline.

I Optical cellular automata (O.C.A.)

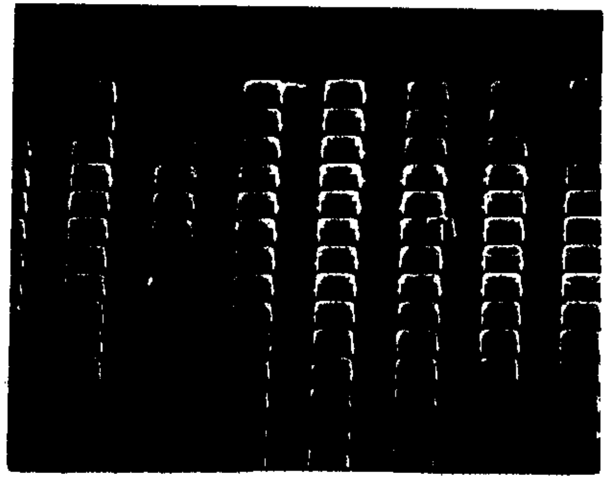
II Interconnects for binary O.C.A.s
- by correlation, relation to triple corr.
- by multiplication

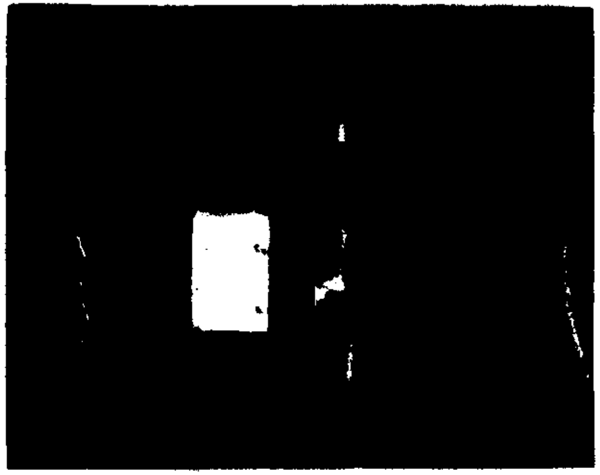
III Optical interconnects for e⁻ computers
- which optical components
- where to put them

IV Conclusion
- basic advantages
- summary

TRIESTE, march '90

Matrice de bistables optiques
(cavités résonnantes en puits quantiques multiples)

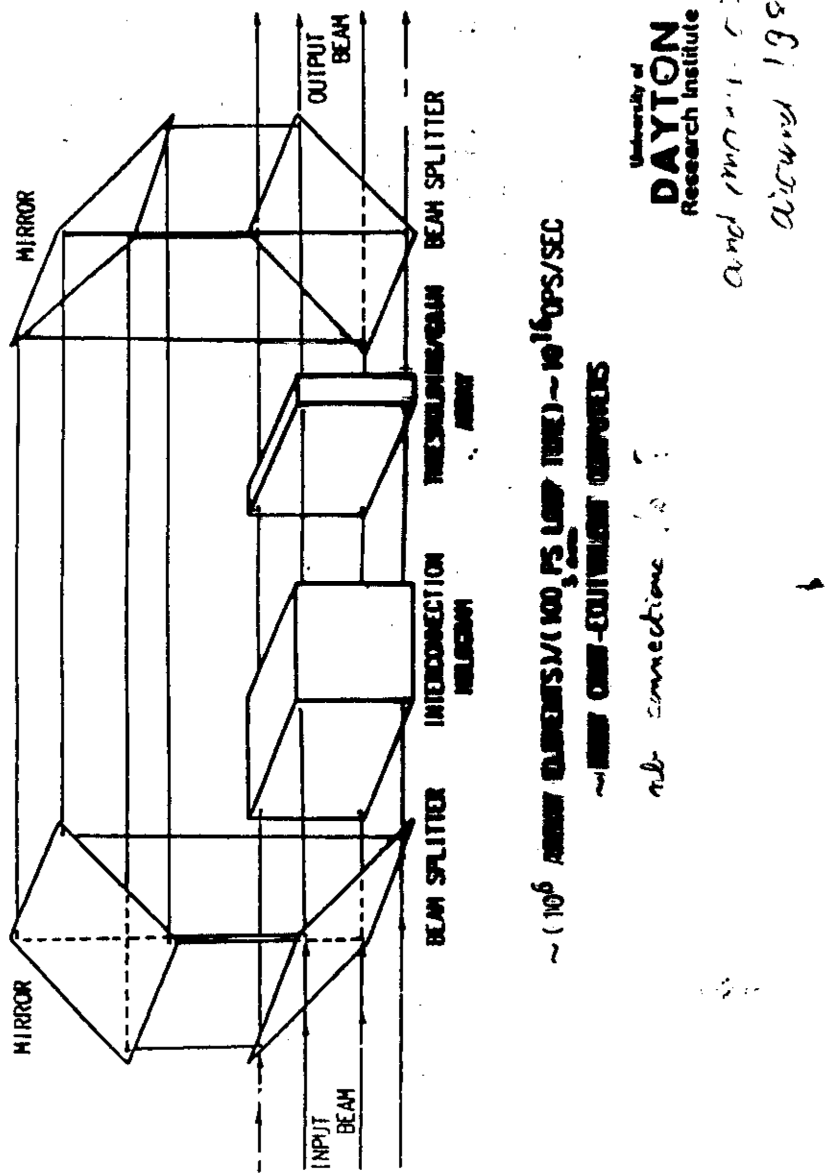




J.L. OUDAR, R. KUSZELEWICZ
1989

1 μm², 1 ns
1 pJ ← optique
10 fJ ← CMOS

ONE POSSIBLE "ULTIMATE" OPTICAL COMPUTER

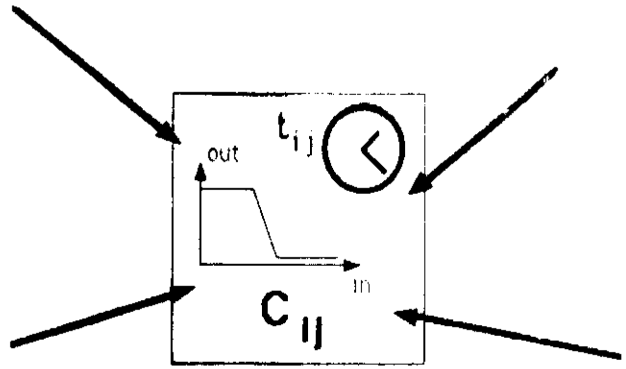


~ (10^6 ARRAY ELEMENTS)/(100 fs LOOP TIME) ~ 10^{16} OPS/SEC

~ 1000 CRAY-EQUIVALENT COMPUTERS

University of DAYTON Research Institute

OPTICAL CELLULAR PROCESSORS (O.C.P.)



one element out of a 2D array

DEFINITION :

- state C_{ij}
- neighborhood V_{ij} = { some of the C_{kl} }
- clock t_{ij}
- equation $C_{ij}(t_{ij}) = f_{ij}(V_{ij}, t_{ij} - 1)$...too general

$$C_{ij}(t_{ij}) = f_{ij}\left(\sum_{V_{ij}} \alpha_{ijkl}\, c_{kl},\ t_{ij} - 1\right)$$

a point non linear operation on a linear combination
"quasi-linear operation" (Athale)

OPTICAL CELLULAR AUTOMATON:

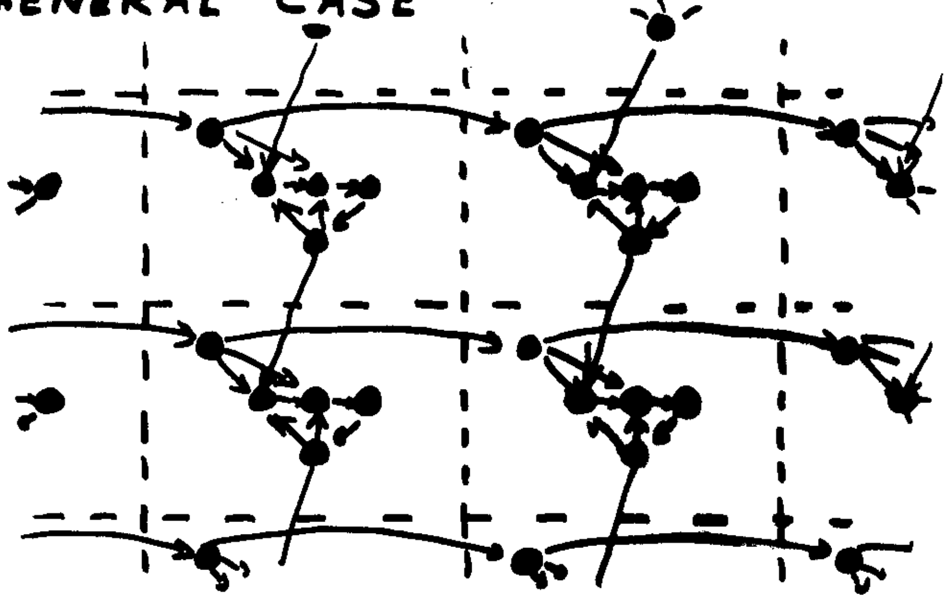
$\alpha_{ijkl} = \alpha_{i-k\ j-l}$ } SHIFT INVARIANCE

$t_{ij} = t$

$\ell_{..} = 0$

CLASSES OF CELLULAR AUTOMATA

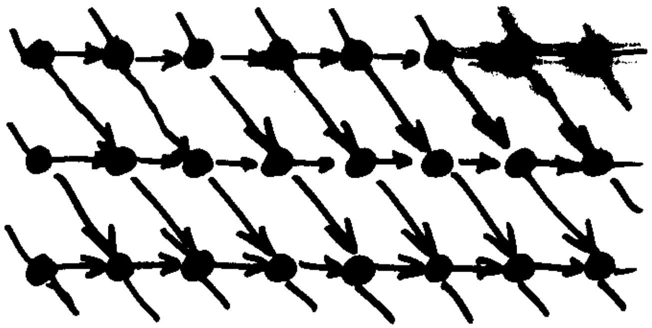
1 - GENERAL CASE



● = non linear device

↖ difficult for optics

2 - MINIMAL GRAIN CELLULAR AUTOMATON



↖ much easier for optics

one n.l. device per cell

<u>complete</u> shift invariance

turbulent flow in duct with obstacle

"von Karmann alley"

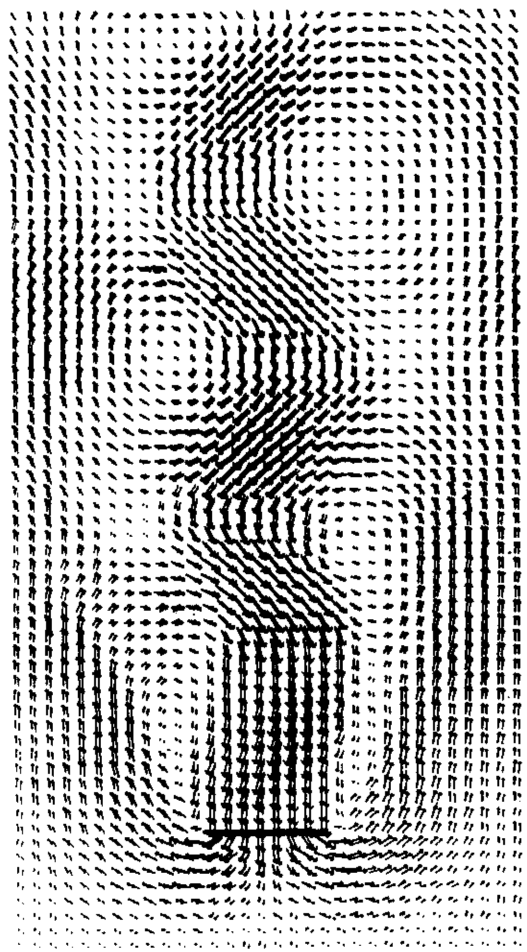


Fig. 2. Écoulement autour d'une plaque mince en mouvement dans le gaz pour un nombre de Reynolds de l'ordre de 90. Les flèches représentent la direction et le module du flux aux nœuds d'un maillage 32 × 64.

D. d'HUMIERES
P. LALLEMAND
Y. POMEAU

Bull. de la SFP n°25 p14-15 (1986)

Binary O.C.A. =

binary <u>pattern</u> <u>recognition</u>

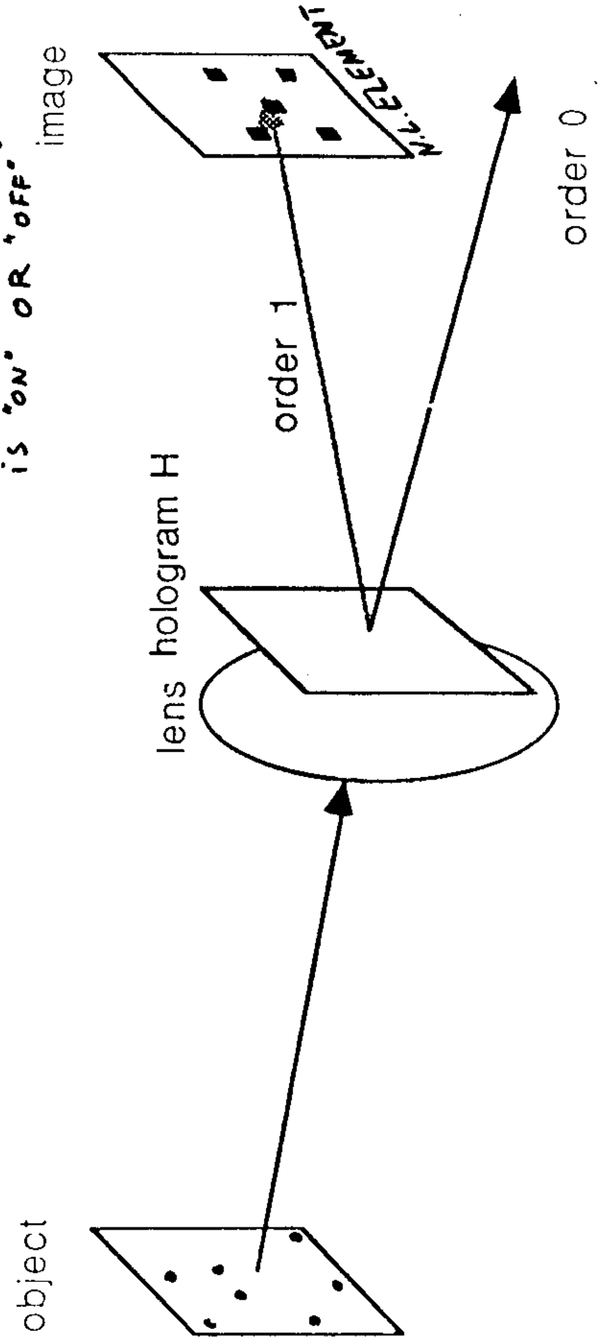
some V's ⤳ ~~amounts~~ to "1"
all others ⤳ "0"

Describe the recognition of <u>one</u> given pattern in neighborhood.

Two ways

1) (Binary) correlation
[relation to 3-correlation and symbolic substitution]

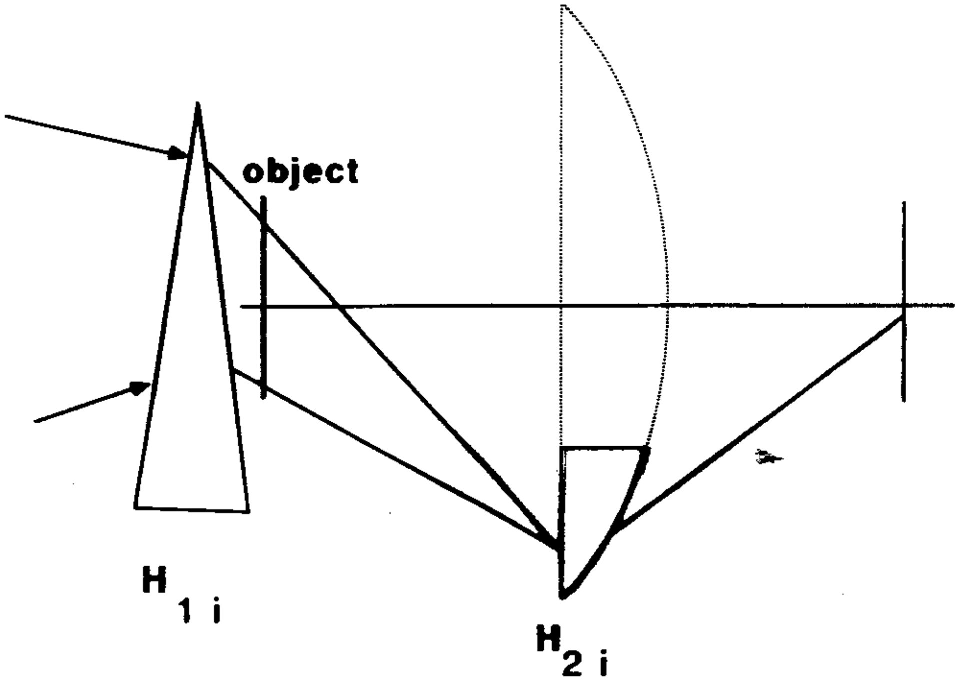
2) multiplication

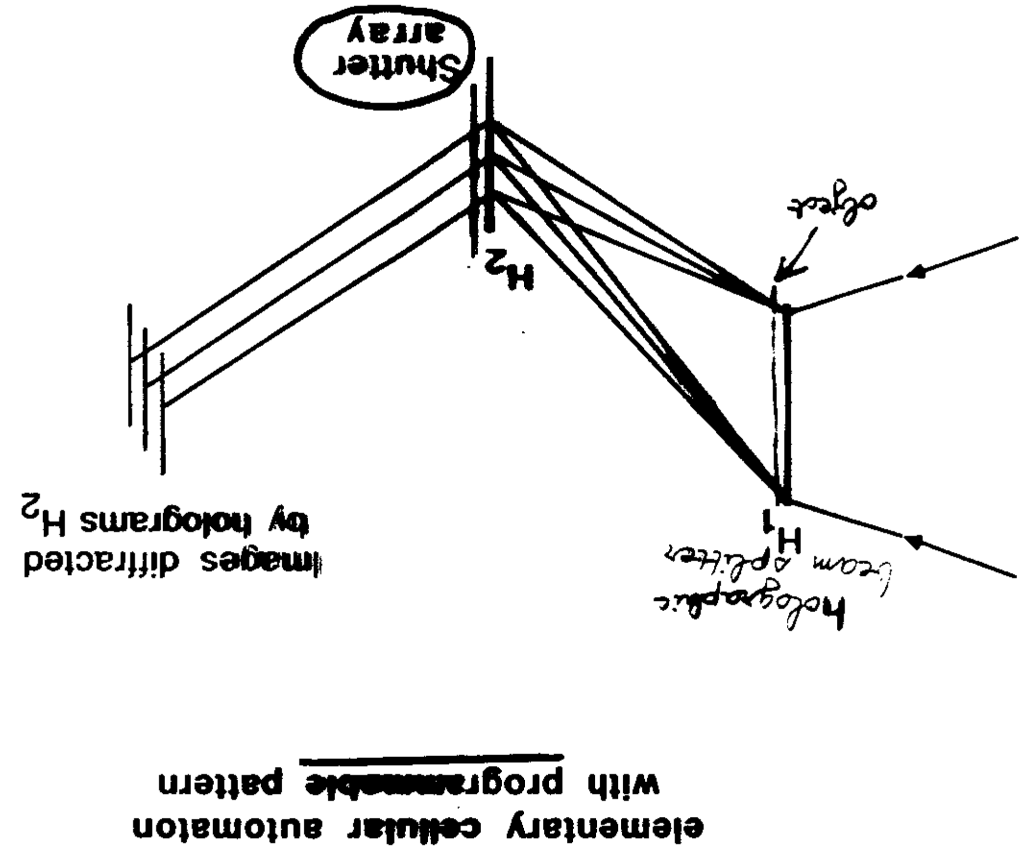


NEED ONLY TO TELL
IF CELL (in image)
IS "ON" OR "OFF"

Figure 1. Absence of light at one point in the image indicates recognition of dark states at each object pixel of pattern M-, in this example an X-shaped 5 pixels pattern.

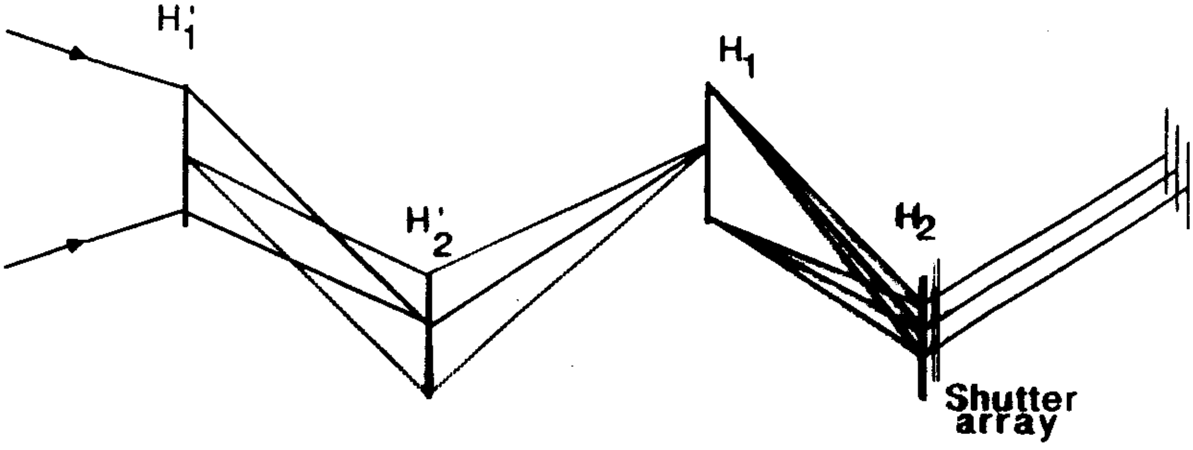
PROBLEM: NEED <u>PROGRAMMABLE</u> MATCH PATTERN refractive optical elements equivalent to one component of each H1 and H2



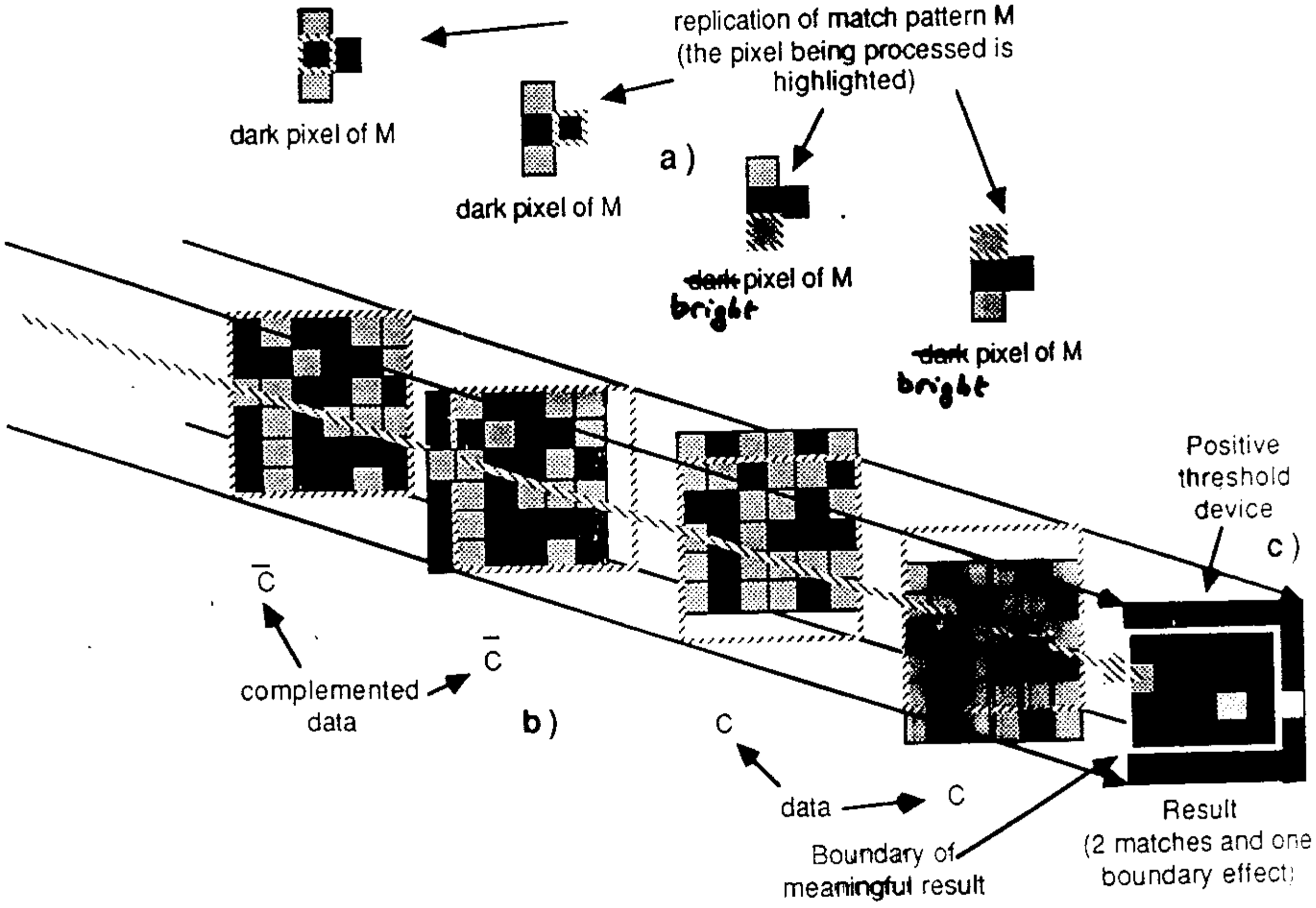


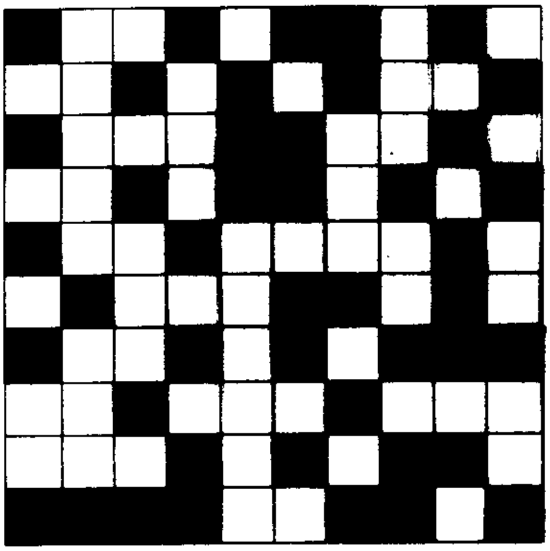
elementary cellular automaton with programmable pattern

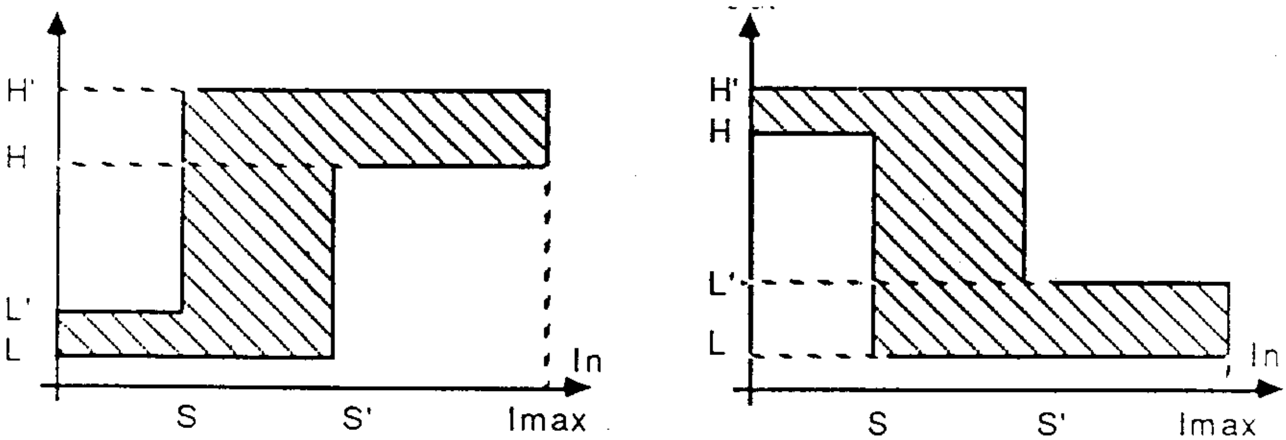
aberration correction
(only distorsion is significant)



residual aberration ⇒ maximum ~ 100 x 100 pixels for a 5 x 5 neighborhood







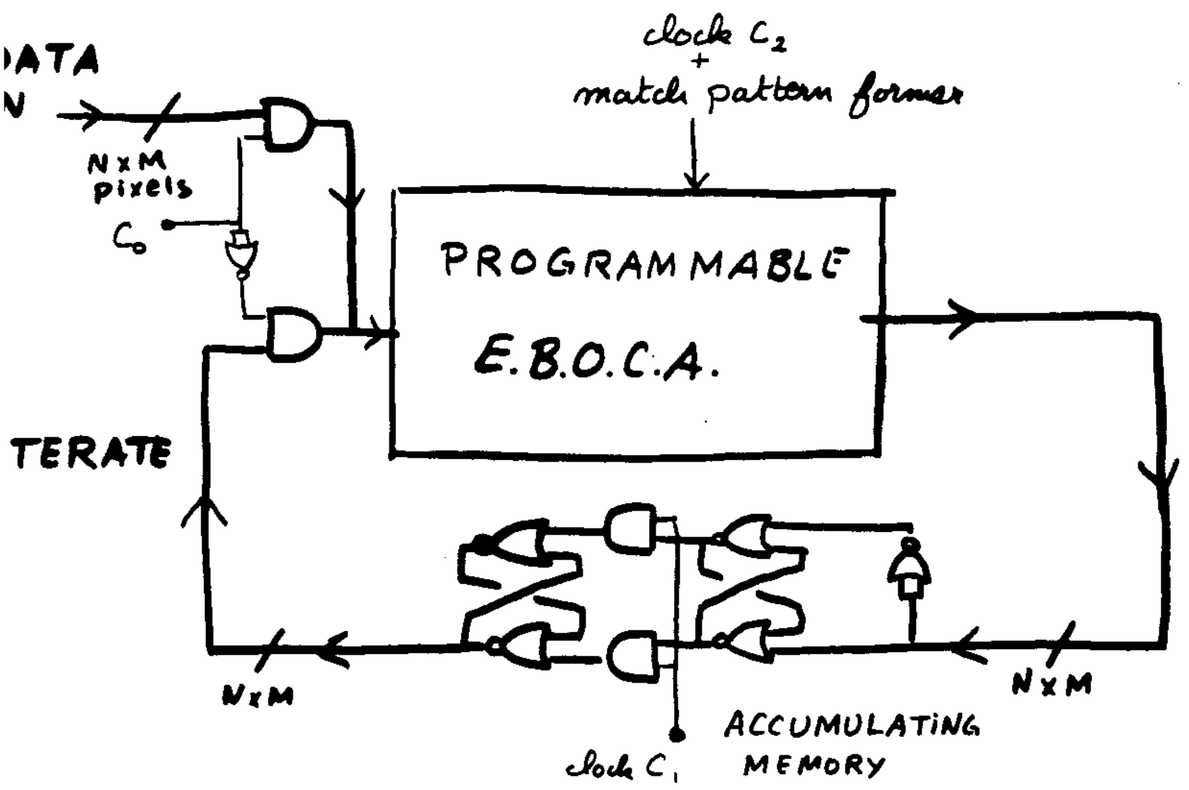
a) b)

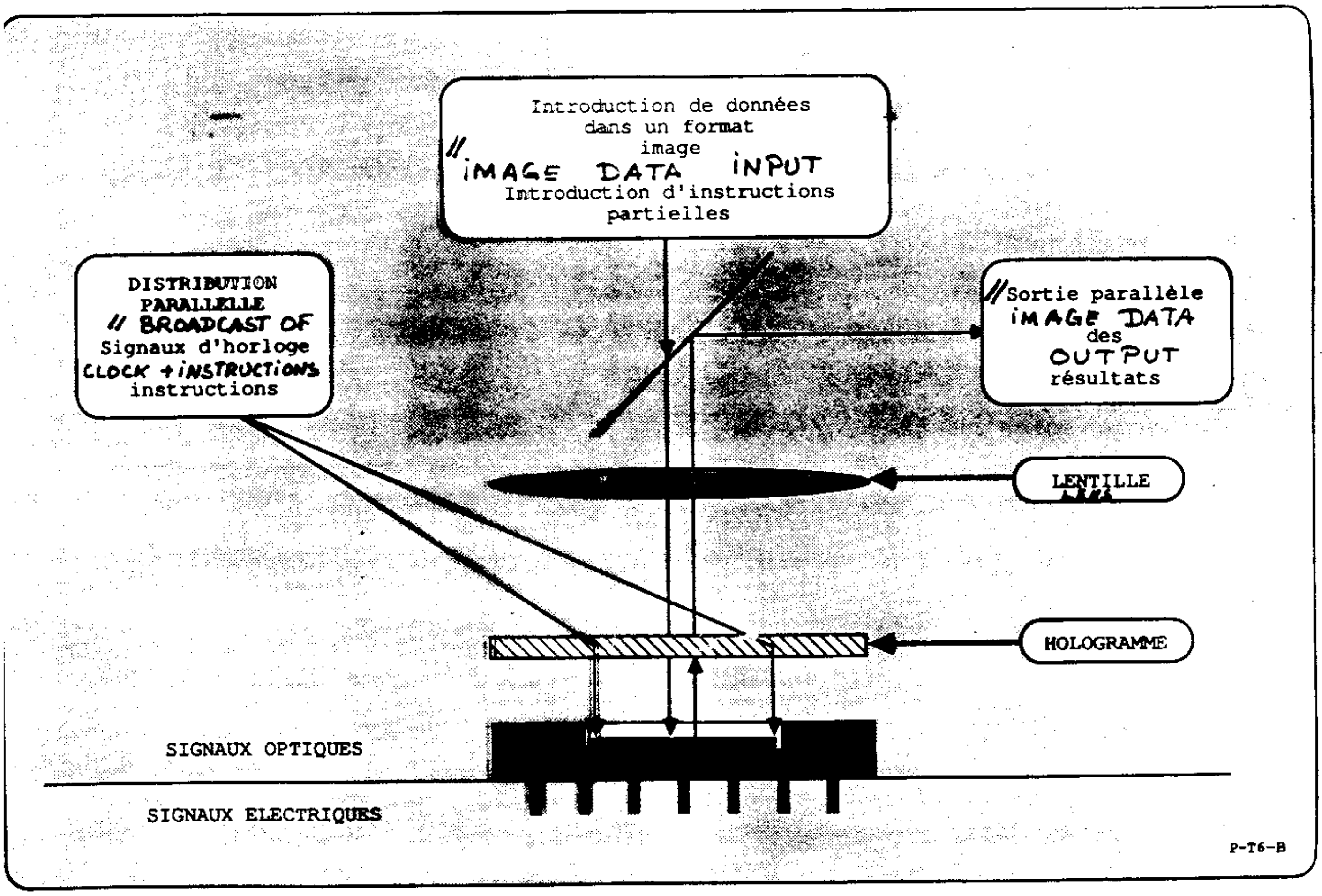
Figure 4. Thresholding.

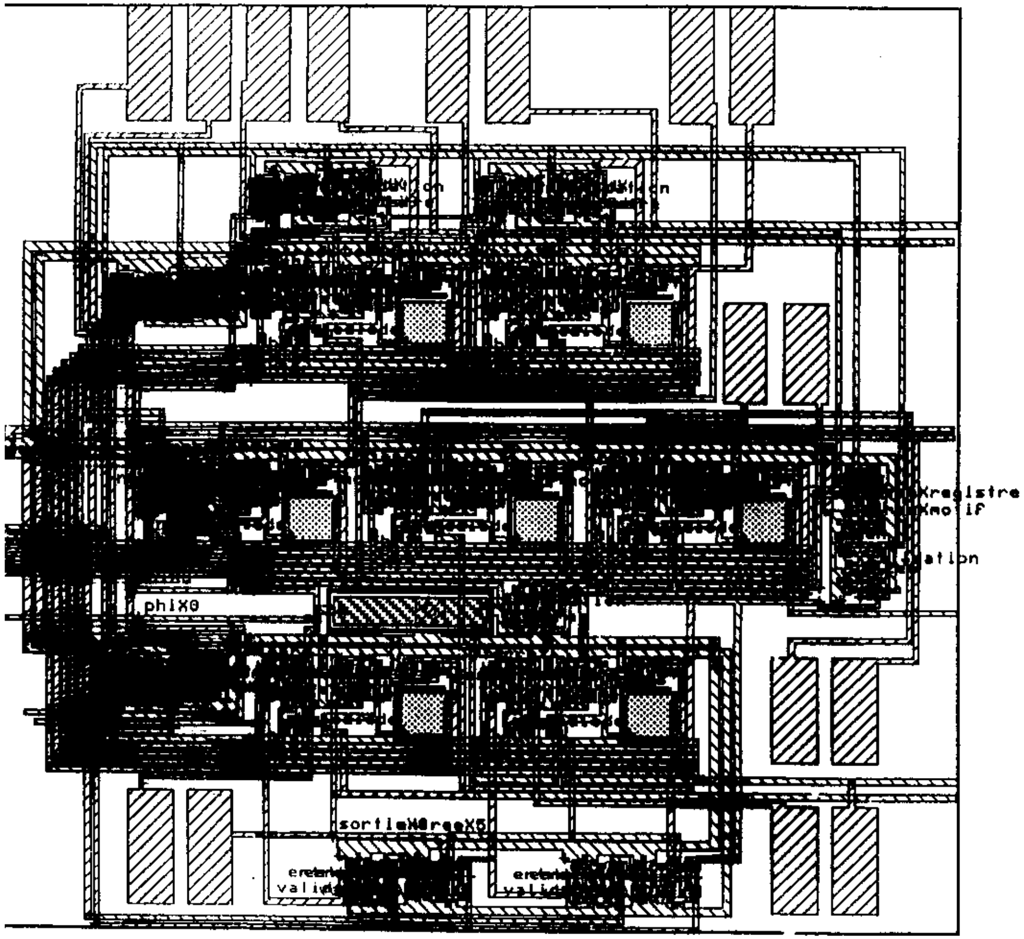
1st approach 1 display + 1 negative threshold device dynamic range D

2nd approach v displays + 1 positive threshold device $\simeq \frac{D}{v}$

COMPLETE BINARY OPTICAL CELLULAR AUTOMATON

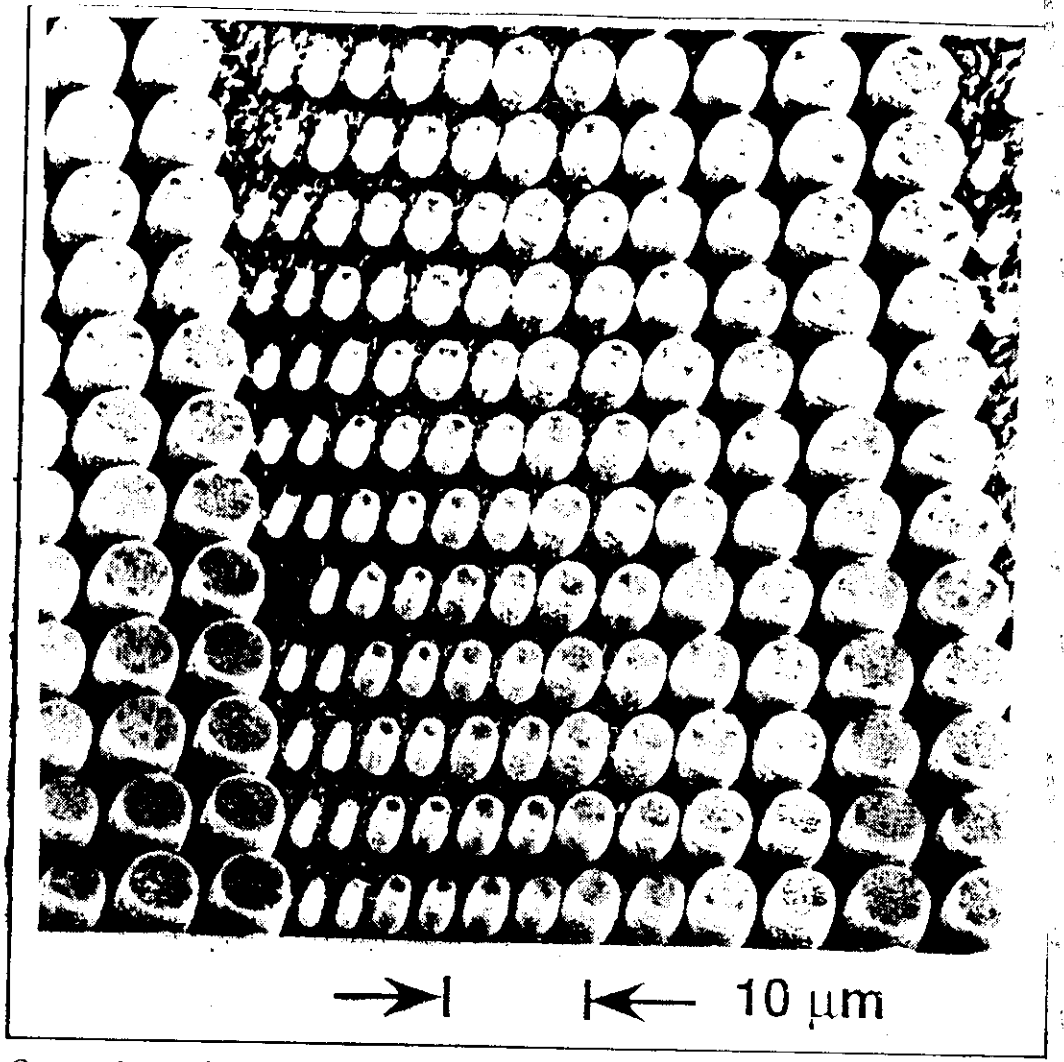






1122.5 µm

[illegible]



Scanning electron micrograph of a small portion of the µ-laser array. Jewell et al., ATT Bell, 1989

2. cont'd

1. How can optics enter computers ? What can optics do for computing ?

(Goodman, Kung, Athale, Leonberger, Proc IEEE 1984)

- Introduce new technological concepts

  • Components : optical bistable matrices (or logic gates)

  • Architectures : symbolic substitution, optical cellular automata

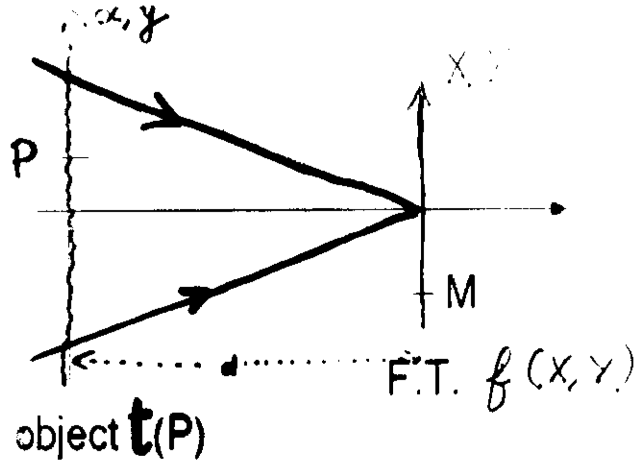
today : optics = 1 pJ, 1μm^2, 1ns
MOS = 10 fJ, 1μm^2, 1ns

- or fill known technological needs

optics up to now has been good :
for connections

computing = { logic + interconnects

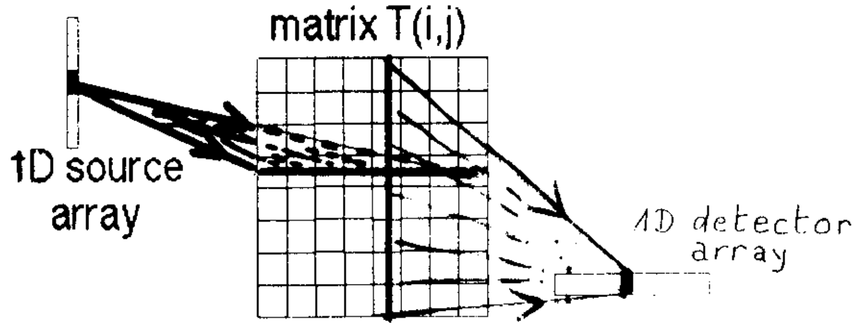
- the optical Fourier transform

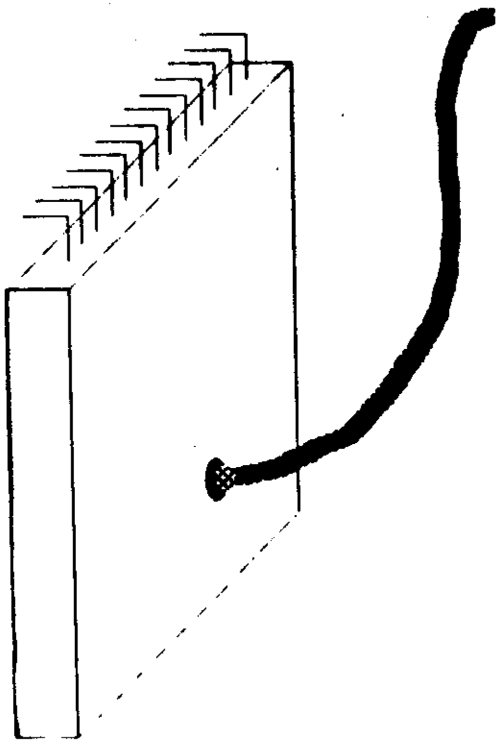


typically worth 10^{12} interconnects
(weighted, analog)

$$f(X,Y) = \alpha \int_{-\infty}^{+\infty} t(x,y) \exp -2i\pi \frac{xX + yY}{2\lambda\ d} dx\ dy$$

- optical matrix multiplication (analog)

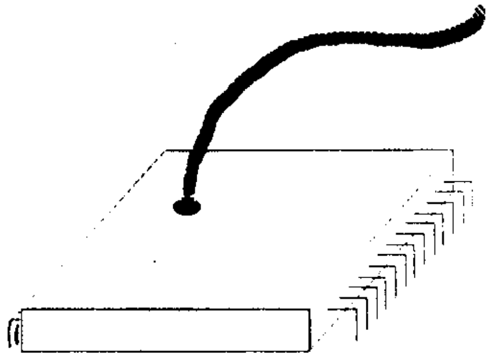




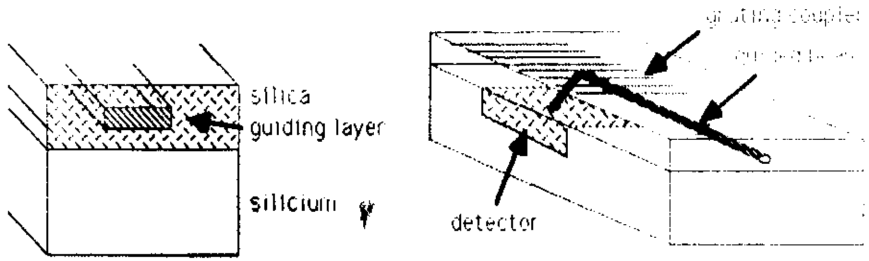
(3) COMPONENTS

3.1 - Optical interconnect components

- guided waves

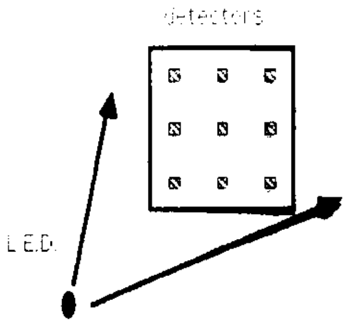


fibers : limited number of beams, but high bandwidth

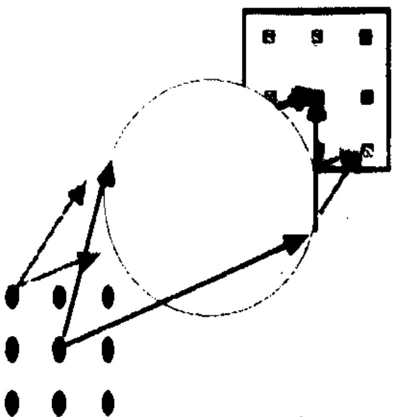


planar guides : geometric compatibility with micro-electronics and 2-D connection density

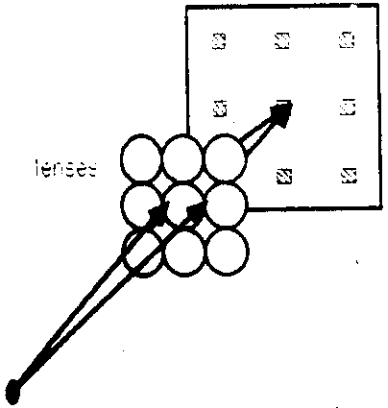
- 3-D components



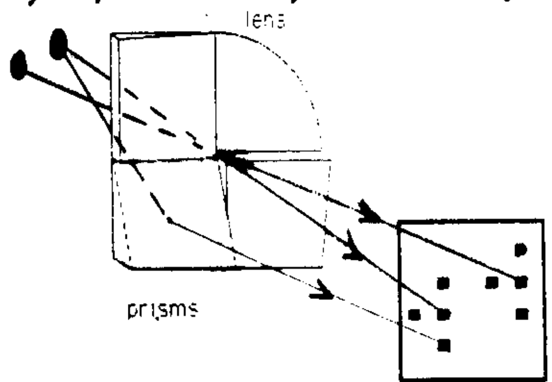
free space : convenient for broadcasting, poor efficiency.



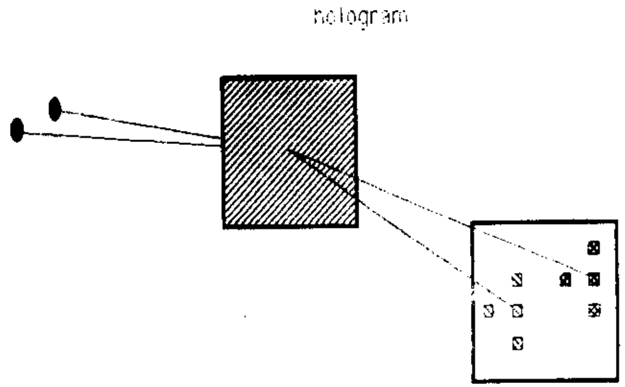
lenses : adequate for imaging (≈1 to 1 connexion)



lenslet arrays improve efficiency in broadcasting

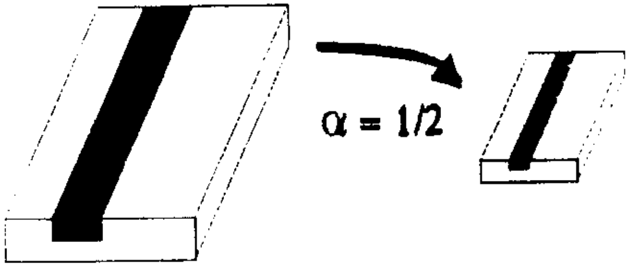


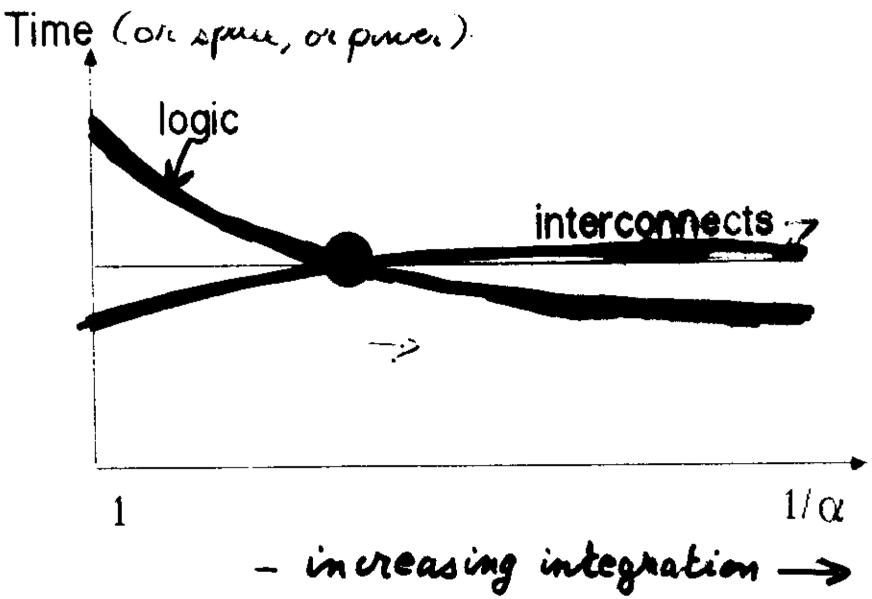
to flexibly combine broadcasting and imaging, use holograms :



Needs for interconnects in computers

- inside chips
  • scaling laws -> interconnects take up relatively more and more space, time, power





Can optics save time/space/power ?

- work by Feldman, Esener, Guest, Lee (U.C.S.D., 1988) compare
  • on-chip electronic connections
  • L.D., free space propagation, photodetection

as a function of frequency and length

optics suffers
  • differential conversion efficiency (source, detector)
  • waste of power because of laser threshold

optics gains
  • no line loss proportional to length (1/2 CV^2)

conclusion : optics is advantageous above a critical interconnection length ℓ_0
for frequency around 10 MHz, ℓ_0 around 1 cm !!

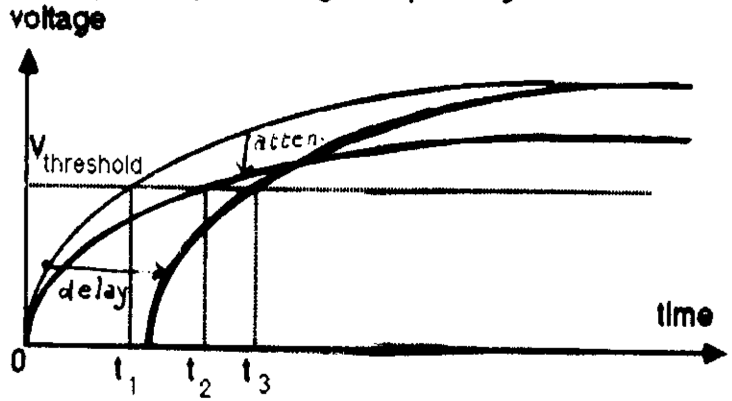
- work by Friedrich, Valette (LETI, Grenoble, 1988) similar conclusions for integrated optics connections ; test in progress.

- suggestion by D.A.B. Miller (A.T.T., 1989) :
  • both ends of an electronic connexion have high impedance ; a line has low impedance, the above gain is an impedance matching through optics ;
  • use optical gates to avoid the threshold problem.

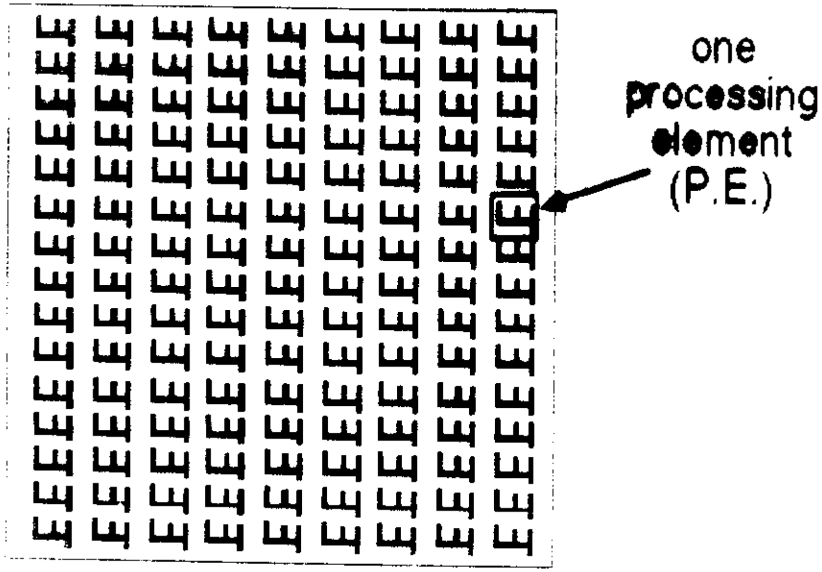
- integration is a challenge ...

• clock skew

affects device synchronization and therefore operating frequency

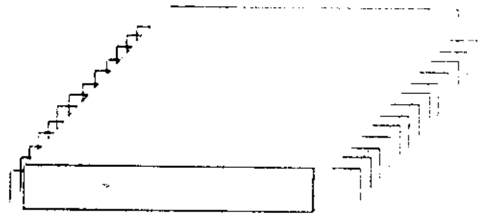


• fine grained parallelism requires more interconnects



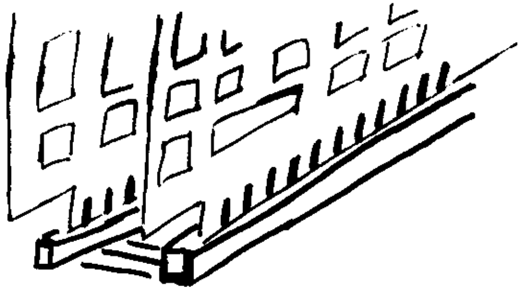
4.2 - between chips

typical number of pins : 200



4.3 - between boards

same limitations : in practice, the clearest limitation to present interconnect technology for fast, parallel, multiboard processors.



B9 **FIRST LABORATORY RESULTS**

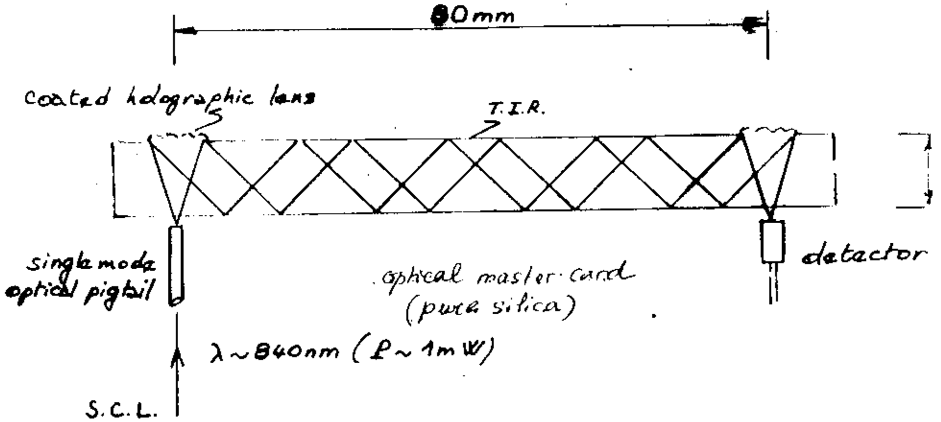
- photoresist ($e \sim 0.4\ \mu m$) SHIPLEY AZ 1350 J
- recording energy density [illegible] $J.cm^{-2}$
- developer [illegible] (1+1)
- development time [illegible] s.

- holographic lens focal length $f = 5\,mm$
- holographic lens diameter $D = 4\,mm$

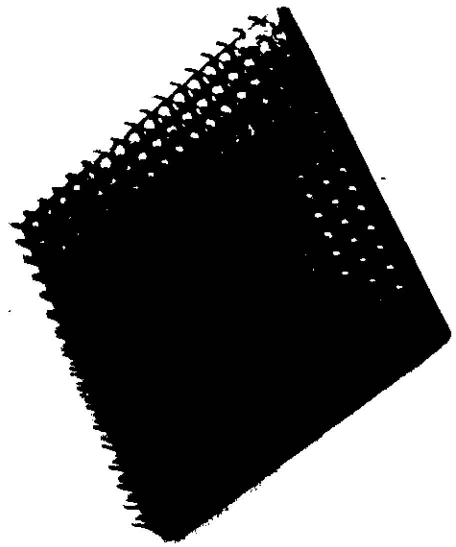
- diffraction efficiency $\simeq 20\%$
- beam divergence $\delta\theta \sim 6'$
  ⇒ éloignement ~ 0,35 mm pour une propagation $L \sim 200\,mm$.

FEASIBILITY DEMONSTRATION OF AN OPTICAL LINK

B10



- low losses in the guide $< 0.05\ dB/cm$
- coupling efficiency $\sim 5\%$
- output focused beam diameter $< 100\ \mu m$

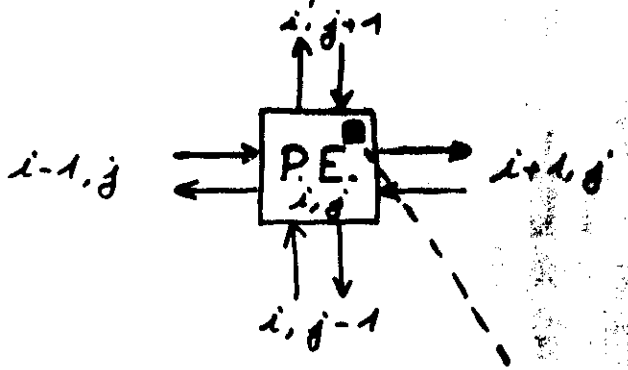


ELECTRONIC MASSIVE PARALLELISM:

- 256 x 256 P.E.s
- ONE CHIP

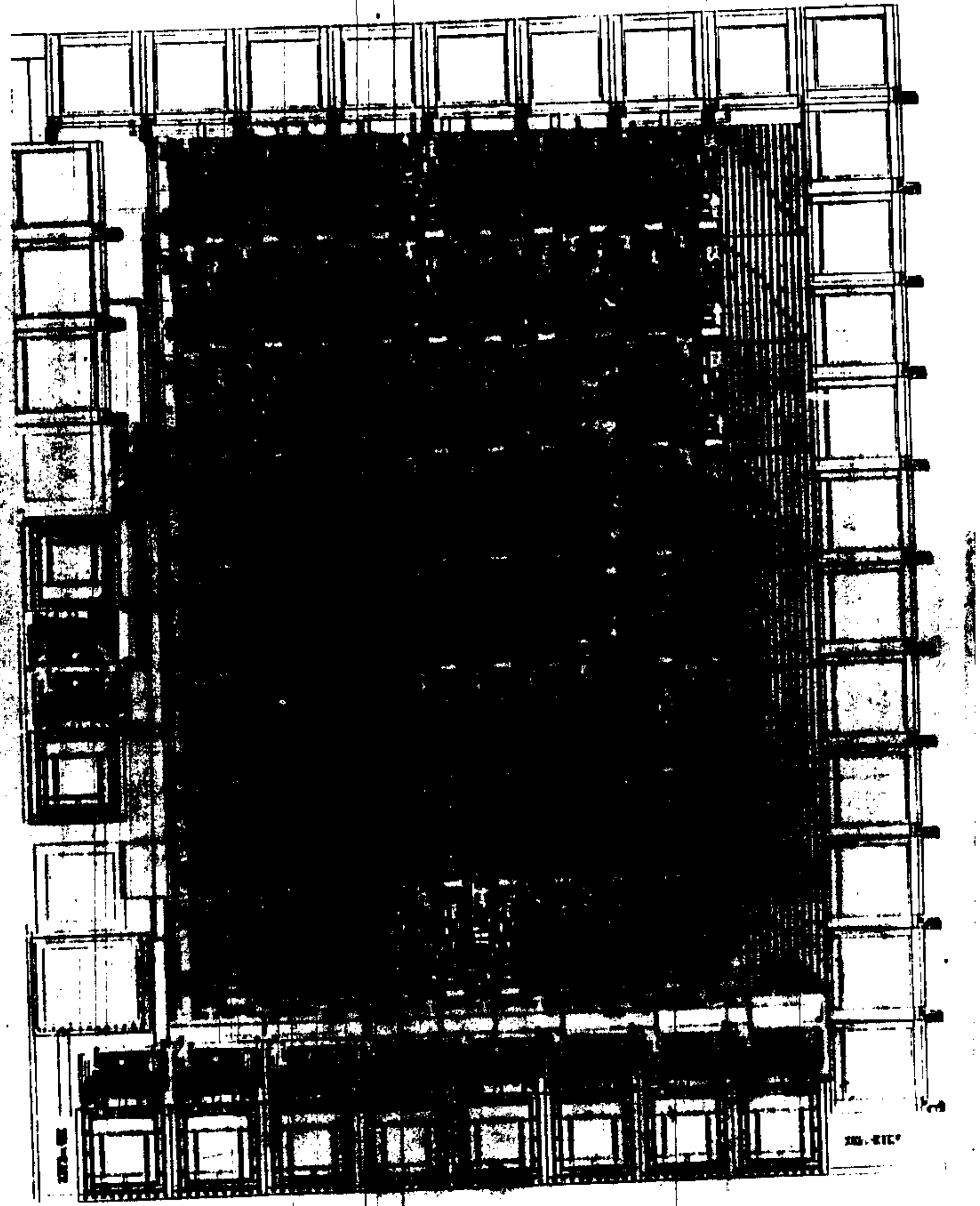
About the PEs:

- ≃ 50 transistors
- 1-bit processor

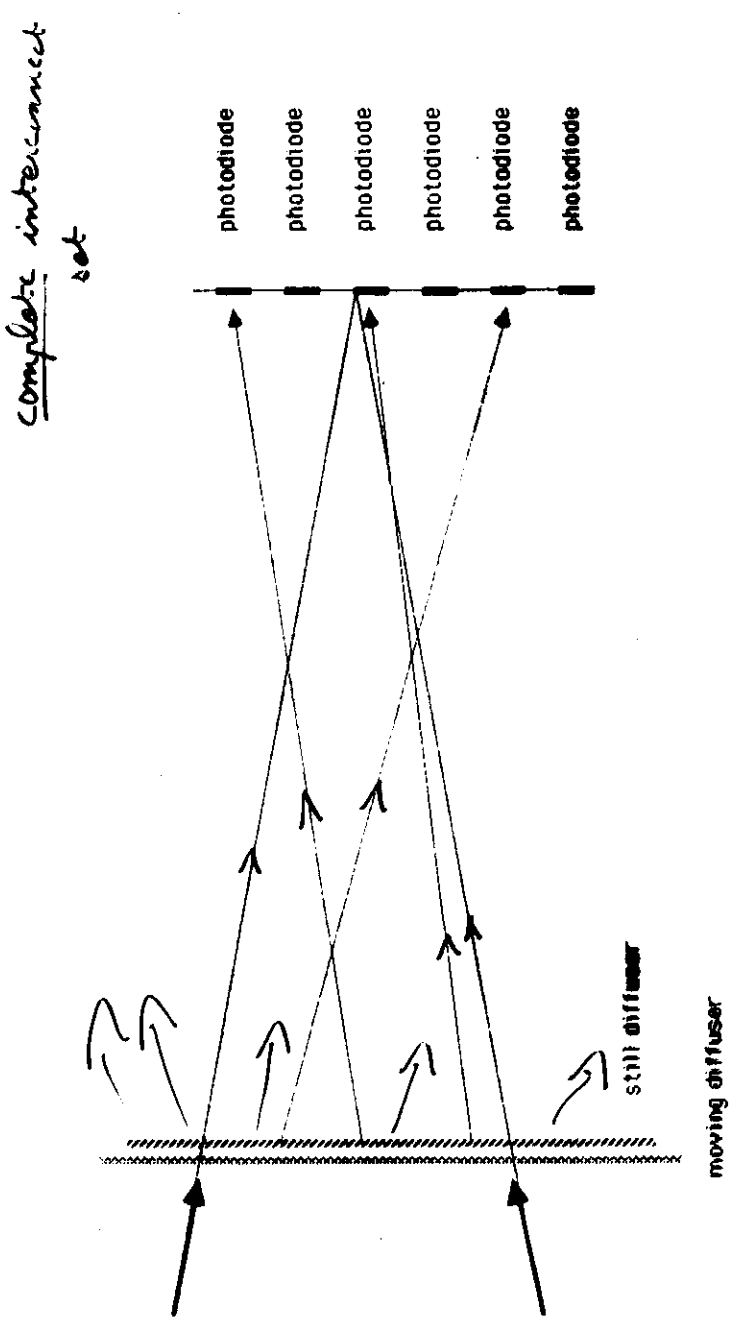


- image format
- includes a photodiode ("SMART RETINA")

OPTICAL GENERATION OF $\sim 10^{10}$ UNCORRELATED RANDOM NUMBERS PER SECOND ON $\sim 1\ cm^2$.



GÉNÉRATION DE NOMBRES ALÉATOIRES POUR PROCESSEURS MASSIVEMENT PARALLÈLES



Generation of random number arrays with speckle

demonstrated: - 10^{-3} residual spatial correlation
- microsecond scale time correlation width.

(5 Conclusions (I)

The advantages of optics

- speed c
    - no ! The Helmholtz equation is the same in optics and in electronics
    - but optical connections save time by an effect of impedance matching
- fan-in/fan-out
    - no ! the power has to be split in any case
    - but optical connections can be extremely dense
- bandwidth
    yes
- reduced crosstalk ("interferences")
    yes

Further research

- integration of optics and microelectronics into OEIC
- develop appropriate microoptics components
- use MQWs and photorefractives as interconnects components
- try to optically interconnect boards.

CONCLUSIONS (II)

Do computers need optics ?

YES : FOR INTERCONNECTS AT LEAST

Do we know what we want to do?

YES : MASSIVELY PARALLEL, "SMALL GRAIN" MACHINES : cellular automata

What do we need to make them ?

(1 micro-optics

(2 o.-e. components

(3 a) microelectronics technology

b) technology for n.l. optics